International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 1065–1076

OPTIMIZATION OF PROCESS PARAMETERS IN WATER JET PEENING ON AA6063 ALUMINIUM ALLOY BY RESPONSE SURFACE METHODOLOGY

D. S. BALAJI[1]* & T. JEYAPOOVAN[2]

[1]*Research Scholar, Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India*

[2]*Professor, Department of Mechanical Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu, India*

ABSTRACT

Water Jet Peening (WJP) is a modern non-traditional surface treatment process which is used to improve the surface integrity of a material. In this study Aluminium Alloy (AA 6063) is subjected to Water jet peening surface treatment. The input process parameters considered are water jet pressure, standoff Distance and Traverse rate and the response parameters used in this study are Hardness (HV) and Surface roughness (R_a). In the present work, the experiments are carried out by Box-Behnken Design (BBD) by Response Surface Methodology (RSM) techniques, which are used to study the influential factor on Water jet Peening process parameters. The experimental result indicates that there is a significant improvement in Hardness and Surface roughness of the peened sample over base sample. The compressive residual stresses were compared to the base sample and no significant changes were observed in the water jet peened surface. Surface hardening takes place over the surface of the peened surface which is shown in the XRD profile.

KEYWORDS: Water Jet Peening, Aluminium Alloy, Response Surface Methodology, Hardness & Surface Roughness

Received: Jul 10, 2019; **Accepted:** Aug 01, 2019; **Published:** Sep 28, 2019; **Paper Id.:** IJMPERDOCT201995

Original Article

INTRODUCTION

Water Jet Peening is a mechanical surface treatment process that creates compressive residual stress by plastic deformation which occurs on the surface of the material to improve the mechanical properties of a material. The working mechanism behind the WJP operation is to produce huge number of aqua droplets from a solid water region which is used for impingement over the surface of the target material. Continuous impingement of water droplets in the target surface results in grain refinement in the subsurface of the material.

Madhulika Srivastava et al., [2018][1] have studied the effect of pulsating water jet peening by using circular and flat nozzles on stainless steel (ANSI 304) by varying traverse speed. Micro hardness values were compared and found that flat nozzles produce better hardness than the circular one. Microstructure examination reveals the plastic deformation which increases the hardness. Xie [2018][8] et al., have developed a surface roughness model to study the effect of surface roughness in biomedical implants. The metal surface under goes plastic deformation and the experiments were carried out by varying the flow velocity from 0 to 700 m/s. Srivastav et al., [2016][1] used water jet peening treatment for welded joints and they found that the prevention of stress corrosion cracking results in the improvement of the residual stress. Manoj et al., [2015] reported that increase in repeated impacts of waterjet droplet will increase the compressive residual stress in target surface.

Arola et al., [2000] [10] have compared water jet (WJ) peening with Abrasive Water jet (AWJ) peening and reported that AWJ peening have produced higher surface roughness due to the effect of high pressure and the presence of garnet abrasive and compressive residual stress of AWJ peening is large when compared to WJ peening. Daniewicz and Cumming et al., [2009] [13] have studied the effect of residual stress on water jet peening on Aluminium Alloy 1100 and found that the generation of residual compressive stress on the peened surface is in the range of 30–60% of the monotonic yield strength in the rolling direction. Yamuchi et al., [1995][2] have compared the cutting and peening process in AL 1050 alloy by varying standoff distance and observed that erosion characteristics were changed in different standoff distances.

Chillman et al., [2007][3] investigates that the effects of high pressure on the surface finish and integrity of the titanium alloy (Ti–6Al–4V) with varied the traverse rates and standoff distance and found that Water Jet Peening at 600 MPa induces a plastic deformation to higher depths in the subsurface layer and also a higher degree of plastic deformation. Ravikumar et al., [2007] studied the surface texture of titanium alloy by pure water jet and AWJ peening operations and reported that residual stress is more in abrasive water jet treatment when compared to water jet treatment.

Rajesh and Ramesh Babu et al., [2001][4] compared flat type nozzle and round type nozzle in water jet peeing and reported that better residual stress is developed at a flat type of nozzle. Toenshoff et al., [1997][5] have carried out water jet peening treatment on hardened steel and found that there is an improvement in fatigue strength of the material and also residual stress are compared with the conventional shot peening and found that there is no significant change in surface roughness and topography of the material.

EXPERIMENTAL WORK

Water jet peening is carried out on NC controlled machine tool of Hi-Cut 3503 make. Aluminum AL6063-T6 alloy was used as work piece material of dimension 100mm x 60 mm x 12mm.In this study, Water Jet Pressure (Mpa), Stand of distance (mm) and Traverse Rate (mm/min) were considered as parameters and peening was carried out with garnet as Abrasive. Experiments were designed using the experiments were conducted by Box-Behnken Design (BBD). Table 1 shows the peening parameters and their levels. The experimental design and observed values of responses are shown in table 2. The chemical composition of AL6063 alloy is shown in the table 3.

Table 1: Specification of Water Jet Peening Setup

Specifications	Type of Nozzle	Orifice Diameter	Focus Tube Diameter	Water Jet Pressure	Abrasive Type	Abrasive Size (grit no)
Value	Round	0.20mm	0.762mm	350mpa	GMT Garnet	80 Mesh

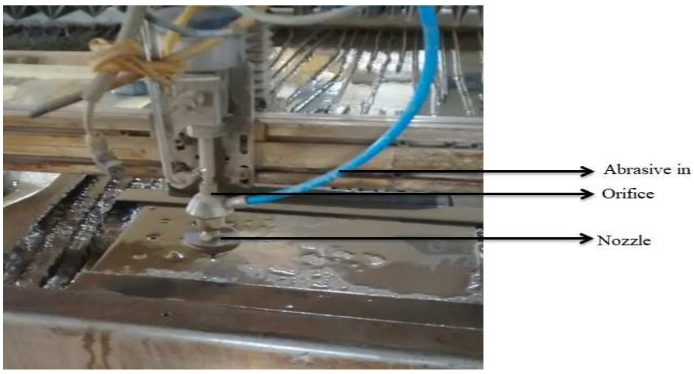

Figure 1: Experimental Setup of Water Jet Peening.

Table 2: Factor and Levels

Sl No	Factors	Units	-1	0	1
1	Water Pressure	Mpa	150	160	170
2	Stand of Distance	mm	80	90	100
3	Traverse Rate	mm/min	1500	1750	2000

Table 3: Chemical Compositions of AA6063-T6

Element	Si.	Mg.	Fe.	Cr.	Cu.	Zn.	Mn.	Ti.	Al.
Weight %	0.6	0.9	0.35	0.10	0.10	0.10	0.10	0.10	97.65

Table 4: Properties of AA6063-T6 Aluminium Alloy

Sl. No	Properties	Values
1	Micro hardness	83 HV
2	Ultimate tensile strength	241 Mpa
3	Yield strength	214 Mpa
4	Modulus of elasticity	68.9 GPa
5	Shear strength	152 Mpa
6	Thermal conductivity	200 w/m/k
7	Melting point	616-654 °C

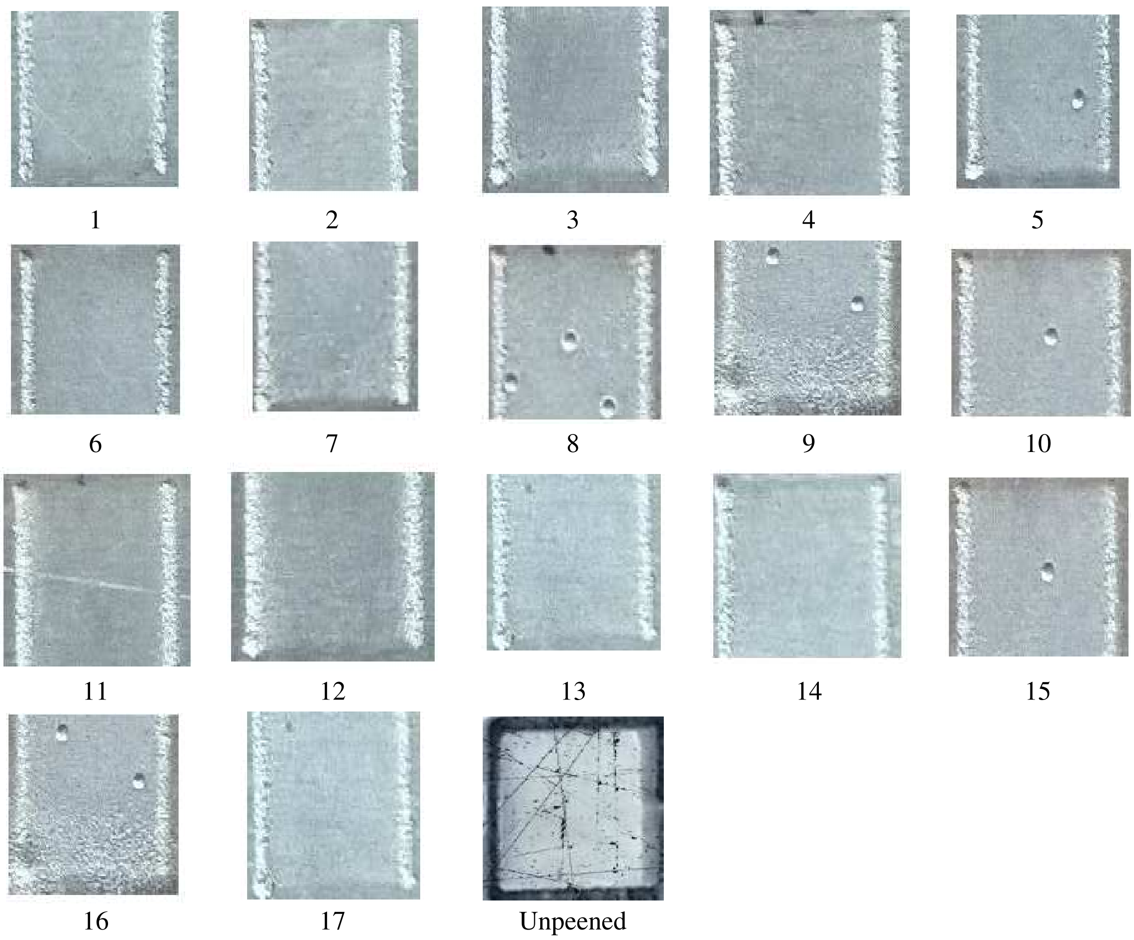

Figure 1(a): Peened Workpiece - Aluminium 6063 Alloy.

Table 5: Box Behnken Experimental Design with Response

Experiment	Water Pressure (Mpa)	Standoff Distance (mm)	Traverse Rate (mm/min)	Vickers Micro Hardness (HV)	Surface Roughness (R_a)
1	-1	-1	0	115.3	3.221
2	1	-1	0	121.3	2.98
3	-1	1	0	108.5	3.526
4	1	1	0	115.3	3.12
5	-1	0	-1	112.5	3.125
6	1	0	-1	121.3	3.23
7	-1	0	1	118.6	3.14
8	1	0	1	121.2	3.154
9	0	-1	-1	119.3	3.236
10	0	1	-1	118.6	3.669
11	0	-1	1	123.5	3.865
12	0	1	1	112.3	3.012
13	0	0	0	107.3	2.983
14	0	0	0	107.5	3.015
15	0	0	0	106.9	2.996
16	0	0	0	107.2	2.994
17	0	0	0	107.6	3.015

The below ANOVA table 6 clearly depicts the Factors, Interaction effects and residuals. It is clearly found that the model for hardness has a significant p-value of <0.001 (<0.05). The F-value of 50.24 shows that the model is significant. There is only a 0.21% chance that an F-value this large could occur due to noise. So, the model for hardness can be accepted. The mathematical model for the hardness is given as follows

$$\text{Hardness} = 107.3 + 3.025*A - 3.0875*B + 0.4875*C + 0.2*A*B - 1.55*A*C - 2.625*B*C + 3.8875*A^2 + 3.9125*B^2 + 7.2125*C^2$$

Table 6: ANOVA for Hardness

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	571.49	9	63.5	50.24	< 0.0001	significant
A-Water Jet Pressure	73.21	1	73.21	57.92	0.0001	
B-Standoff Distance	76.26	1	76.26	60.34	0.0001	
C-Traverse Rate	1.9	1	1.9	1.5	0.2597	
AB	0.16	1	0.16	0.1266	0.7325	
AC	9.61	1	9.61	7.6	0.0282	
BC	27.56	1	27.56	21.81	0.0023	
A^2	63.63	1	63.63	50.34	0.0002	
B^2	64.45	1	64.45	50.99	0.0002	
C^2	219.03	1	219.03	173.29	< 0.0001	
Residual	8.85	7	1.26			
Lack of Fit	8.55	3	2.85	37.99	0.0021	significant
Pure Error	0.3	4	0.075			
Total	580.34	16				

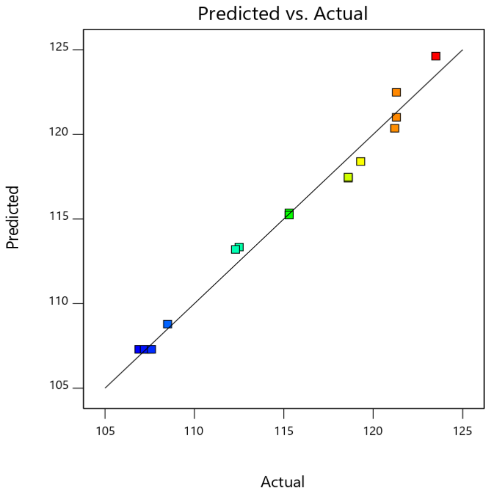

Figure 2: Relationship between Predicted and Actual Hardness.

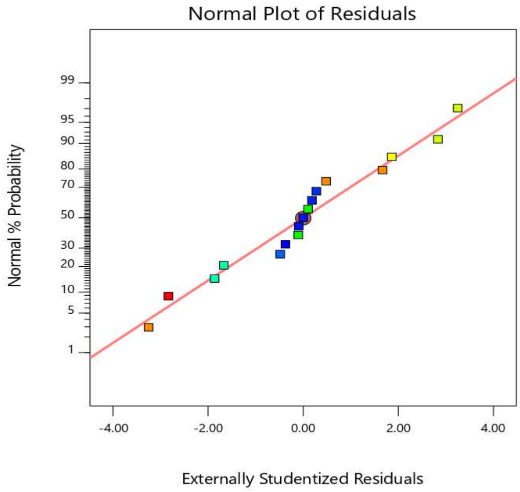

Figure 3: Normal Plot of Residuals for Hardness.

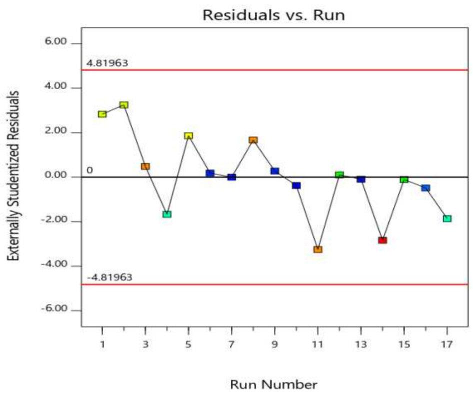

Figure 4: Residuals Variations Over Runs.

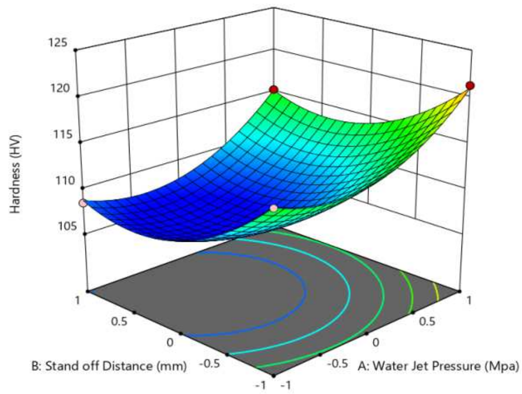

Figure 5: Effect of Waterjet Pressure and Standoff Distance on Hardness.

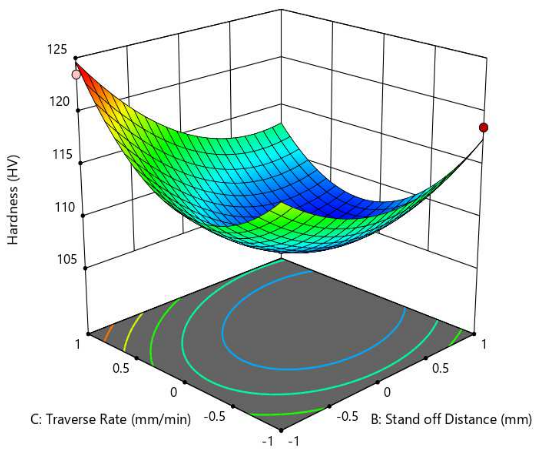

Figure 6: Effect of Standoff Distance and Traverse Rate on Hardness.

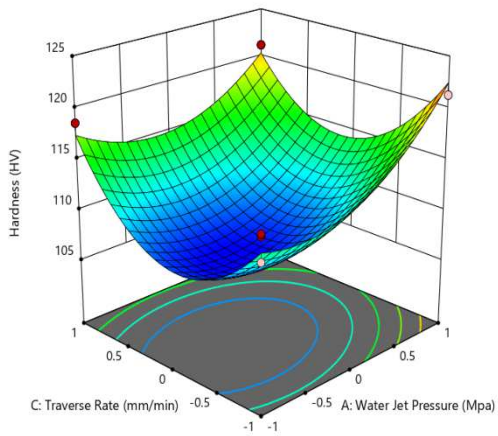

Figure 7: Effect of Waterjet Pressure and Traverse Rate on Hardness.

Table 7: ANOVA for Surface Roughness

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.9035	9	0.1004	4.19	0.0361	significant
A-Water Jet Pressure	0.0348	1	0.0348	1.45	0.2671	
B-Standoff Distance	0.0001	1	0.0001	0.0033	0.9561	
C-Traverse Rate	0.001	1	0.001	0.0413	0.8447	
AB	0.0068	1	0.0068	0.2839	0.6106	
AC	0.0021	1	0.0021	0.0864	0.7774	
BC	0.4134	1	0.4134	17.25	0.0043	
A^2	0.0055	1	0.0055	0.2283	0.6474	
B^2	0.2573	1	0.2573	10.73	0.0136	
C^2	0.1646	1	0.1646	6.87	0.0344	
Residual	0.1678	7	0.024			
Lack of Fit	0.167	3	0.0557	282.16	< 0.0001	significant
Pure Error	0.0008	4	0.0002			
Total	1.07	16				

The above ANOVA Table 7 clearly depicts the Factors, Interaction effects and residuals. It is clearly found that the model for surface roughness has a significant p-value of 0.0361 (<0.05). The F-value of 4.19 shows that the model is significant. There is only a 3.61% chance that an F-value this large could occur due to noise. So, the model for surface roughness can be accepted. The mathematical model for the surface roughness is given as follows:

Surface Roughness $=3.0006-0.066*A+0.003125*B-0.011125*C-0.04125*A*B-0.02275*A*C-0.3215*B*C-0.03605*A^2+0.2472*B^2+0.1977*C^2$

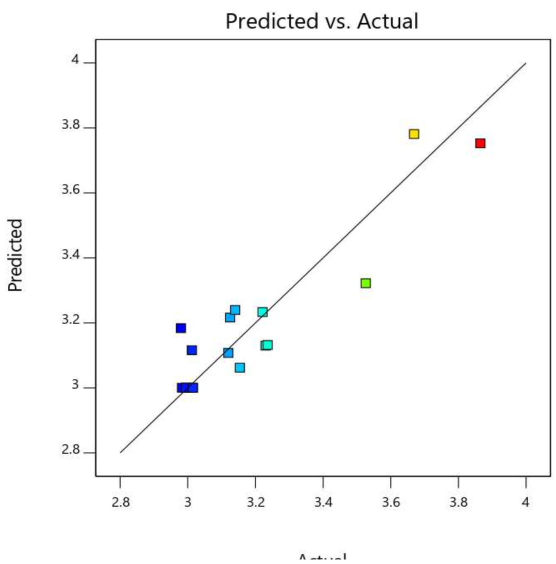

Figure 8: Relationship Between Predicted and Actual Surface Roughness.

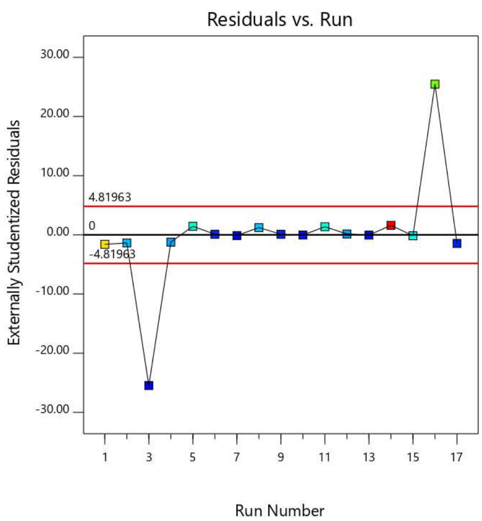

Figure 9: Residuals Variations Over Runs.

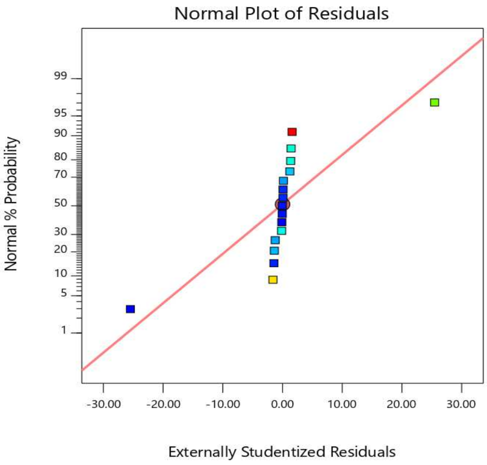

Figure 10: Normal Plot of Residuals for Hardness.

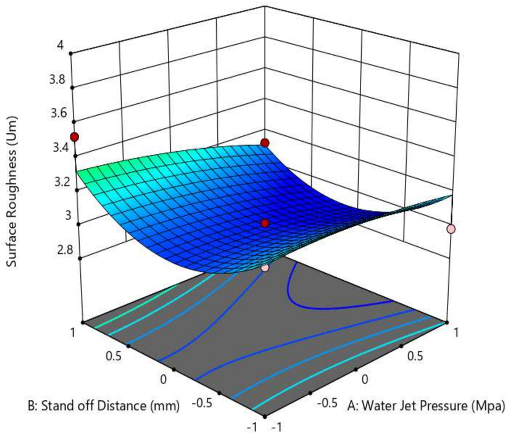

Figure 11: Effect of Waterjet Pressure and Standoff Distance on Surface Roughness.

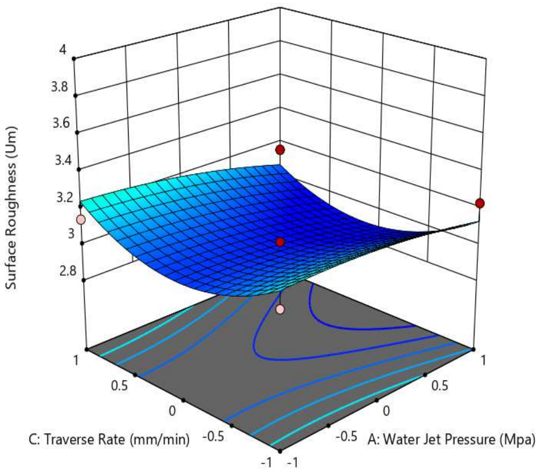

Figure 12: Effect of Waterjet Pressure and Traverse Rate on Hardness

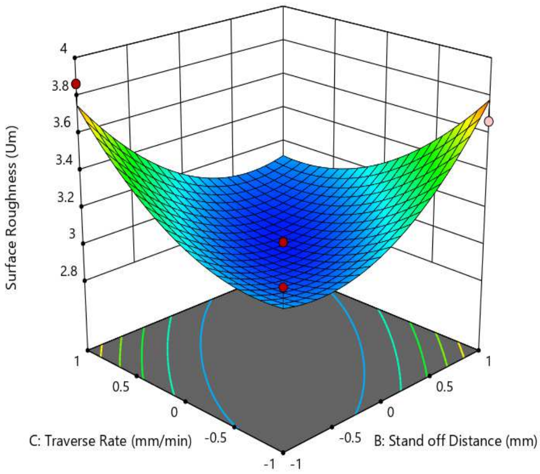

Figure 13: Effect of Standoff Distance and Traverse Rate on Surface Roughness

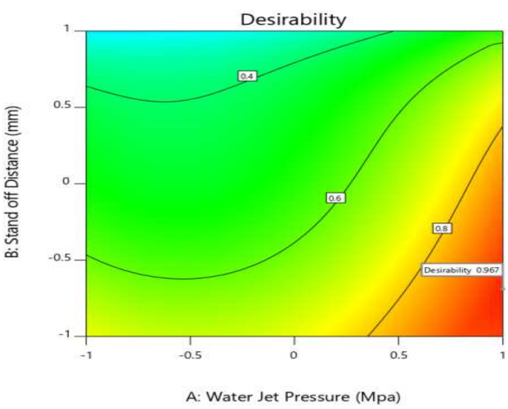

Figure 14: Desirability of Water Jet Pressure and Standoff Distance.

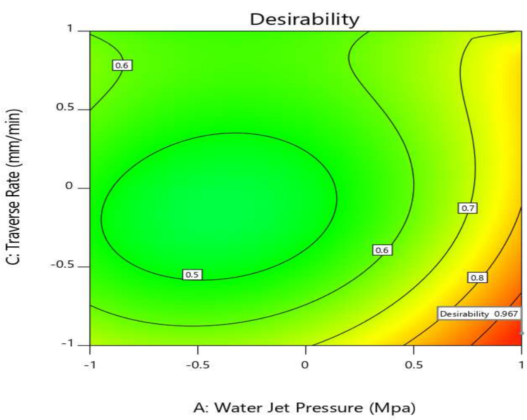

Figure 15: Desirability of Water Jet Pressure Traverse Rate.

The overall model desirability of AB, AC, and BC the is found to be 0.967 which confirms that the RSM model is significant. Table 5 shows the optimal solution that has water jet pressure of 170 Mpa , Standoff Distance of 83.115 mm and Traverse rate of 1519.49 mm/min with the corresponding hardness of 123.5 HV and Surface roughness of 3.037μ

RESULT AND DISCUSSIONS

Effect of Peening Parameters on Micro-Hardness

A Vickers Micro hardness tester has been used to measure the hardness of the sample, vicker's hardness testing machine uses a diamond intend with a load of 0.1 kg and a dwell time of 10 sec. The increase in hardness value was observed after peening, the minimum hardness was observed as 106.9 HV and the maximum hardness was observed as 123.5 HV. The higher hardness value is obtained due to the combined effect of 160 Mpa water jet pressure, 80 mm Standoff Distance and 2000 mm/min Traverse rate. The higher hardness value is observed due to the significant contribution of water jet pressure, Standoff Distance and Traverse rate was influenced in the peened region. Water jet pressure and Traverse rate increases the intensity of the water jet which causes the plastic deformation. In the WJP process, every drop of water gains a kinetic energy and impacts on the surface with a maximum load, which increases the yield strength of the material in minimum time. It is produced due to the distribution of pressure in the water droplets during the impingement on the target sample. After these water droplets break down on the target surface, compressive pressure waves are produced on the surface. This action helps in creating a plastic deformation induced in the material.

Effect of Peening Parameters on Surface Roughness

A surface roughness measuring machine, SURFCORDER SE 3500, from Kosaka Laboratories is used in this work to measure the surface roughness of the peened sample. It has an interchangeable stylus arm that scans the surface of the sample. The stylus is attached to the data acquisition system of the machine and is used to calculate the value of surface roughness. The surface roughness (R_a) for an unpeened sample is measured as 2.92 μm and for peened samples it is found to be 3.12 μ. A lower surface roughness of 2.994 μ was reported due to the combined contribution of Water jet Pressure(160 Mpa), standoff distance (90mm) and Traverse rate (1750mm/min). A lower surface roughness is reported due the occurrence of uniform erosion in the surface and higher surface roughness of 3.865μ is reported due to the combined effect of Water jet Pressure(160 Mpa), standoff distance (80mm) and Traverse rate (2000mm/min). An occurrence of high surface roughness is due to the round type nozzle which can cover a larger area than any other type of nozzle. Due to this effect randomness in distribution of water droplets can fluctuate the power on the metallic surface. This shows that selection of nozzle plays a predominant role in affecting the surface properties of materials.

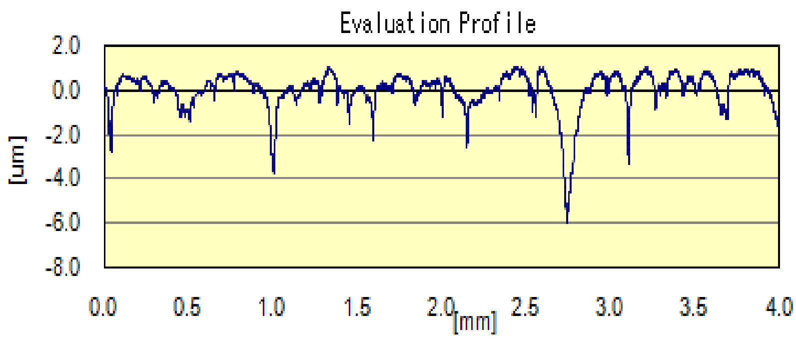

Figure 17: Surface Roughness Profile of Unpeened Sample.

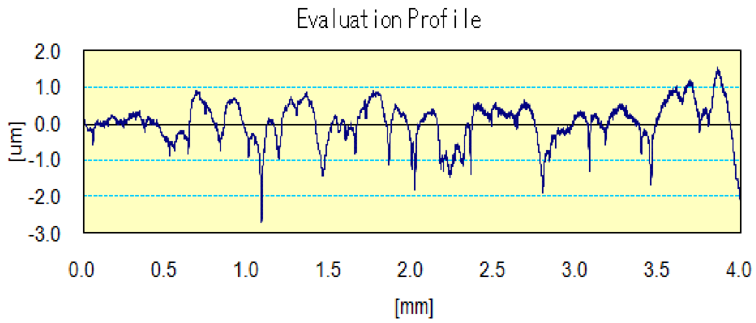

Figure 18: Surface Roughness Profile of Peened Sample.

Effect of Peening Parameters on Microstructure

Figures 19 and 20 shows the microstructure of unpeened and peened samples. There is no visible crack or tear found on the treated surface. This confirms the occurrence of deformation on the peened surface which causes the plastic deformation and thereby the hardness of the material is increased up to 33%. From the microstructure it is found that there is a deposition of abrasive particles on the peened surface. The effect of randomness was observed in the water jet peened material and this was due to the impact of water at high velocity created on the round nozzle

Effect of Peening Parameters on Residual Stress

Figures 24 and 25 shows the XRD profile of an unpeened sample and peened sample respectively. The XRD result shows the variation in peak (111) shifts in the peened samples. The ‘d’ spacing value of XRD profile is found as 2.359 Å and for peened samples it is found as 2.165 Å and 2.193 Å respectively. There is an increase in compressive residual stress of a peened sample due to the reduction of ‘d’ spacing which confirms that there is a severe impingement of water that strikes the target material which there by increases the hardness of the material. This happened due to the surface deformation occurrence during water impingement. The variation in peak intensity is observed in peening process due to the variation in roughness of the peened sample. The proper selection of process parameters such as Standoff Distance, Water jet Pressure and Standoff Distance shows a predominant role in improving the compressive residual stress by creating the deformation in the surface regions

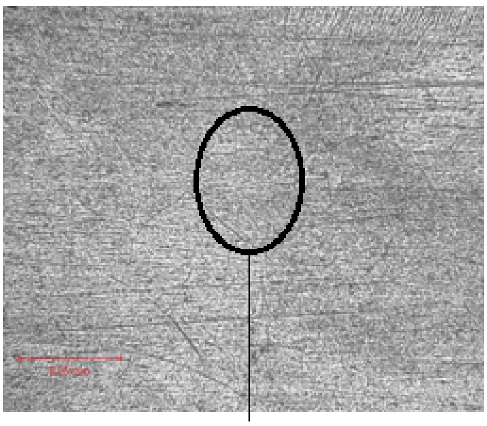

Figure 19: Microstructure of the Sample before Peening.

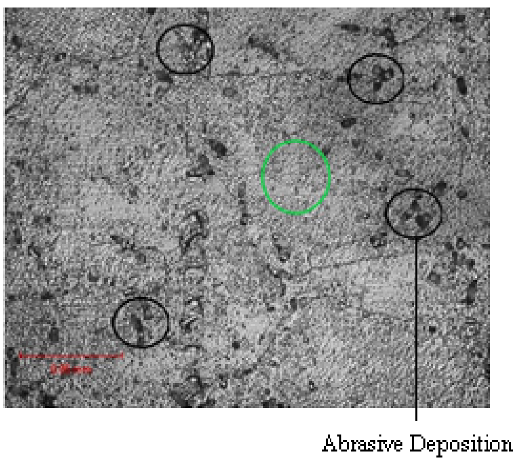

Figure 20: Microstructure of the Sample after Peening.

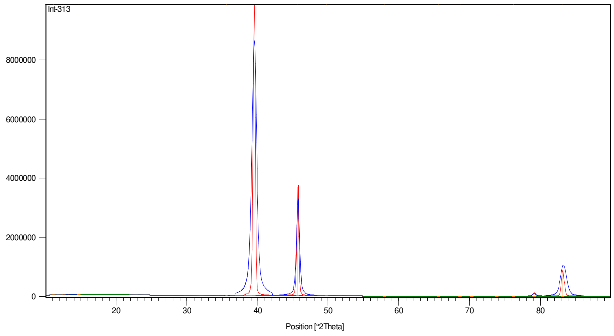

Figure 21: XRD Peaks of Unpeened Sample.

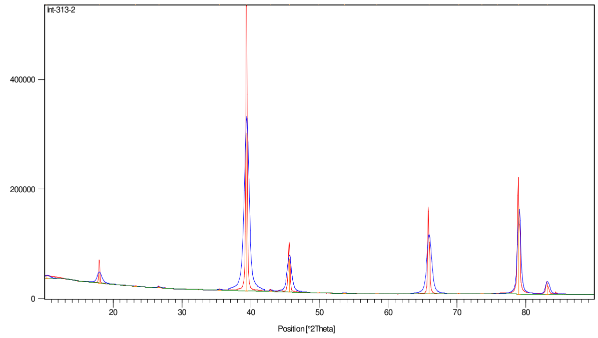

Figure 22: XRD Peaks of Peened Sample.

Table 8: Compressive Residual Stress Values

Water Jet Peened Conditions	2θ	Peek Intensity Range	Peak Reflection Plane	d spacing (A^o)	Compressive Residual Stress (MPa)
Base metal	39.548	718.36	111	2.359	–69.748
Experiment 1	45.268	659.25	111	2.165	–79.667
Experiment 2	45.547	494.44	111	2.193	–78.959

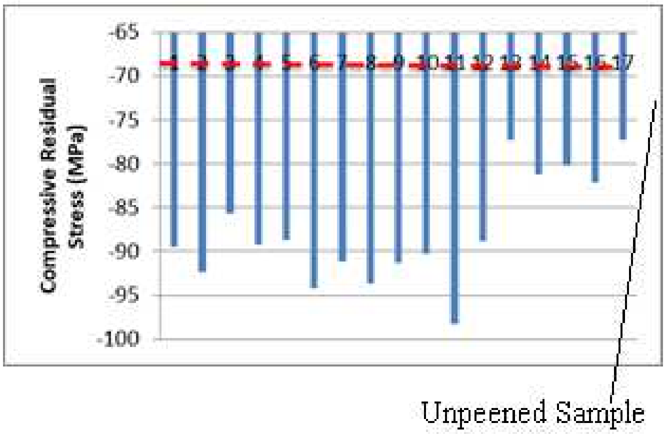

Figure 23: Compressive Residual Stresses of Peened and Unpeened Sample.

CONCLUSIONS

The following major conclusions are drawn during the water jet peening on AL6063-T6 Aluminium Alloy by Box-Bhenken experimental approach under Response surface methodology. The XRD profile, residual stress and microstructure were carried out.

- There was a significant improvement in micro hardness of the peened sample up to 33% by work hardening effect under water jet peened operation. The SEM image comparison between the Unpeened and Peened material shows the change of grain structure which is the reason for hardness improvement.
- The surface roughness was increased up to 8% and a lower value of 2.98µ was observed. This was due to the combined effect of pressure 170 Mpa, Standoff distance 80 mm and Traverse rate 1750 mm/min. This peening operation provides softer erosion on the targeted surface.

- A comparison is made between the experimental results and predicted results based on the responses of hardness and surface roughness and it is found that the values are linear. The ANOVA results confirm that the models were significant.
- The XRD peaks further confirm that there is no significant change observed between the samples, which is confirmed by the production of similar values of compressive residual stress and this happens due to the effect of variations on the erosion surface through round nozzle.
- Micro structure clearly reveals the effect of water jet peening operation in the material.

REFERENCES

1. *Madhulika Srivastava, Sergej Hloch, Rupam Tripathi, Drazan Kozak, Somnath Chattopadhyaya, Amit Rai Dixit, Josef Foldyna, Pavol Hvizdos, Martin Fides, Pavel Adamcik, Ultrasonically generated pulsed water jet peening of austenitic stainless-steel surfaces, Journal of Manufacturing Processes, vol. 32, 2018, p.455–468 pp, ISSN 1526–6125.*
2. *Chillman, A. & Ramulu, M. & Hashish, Mohamed. (2007). Waterjet Peening and Surface Preparation at 600 MPa: A Preliminary Experimental Study. Journal of Fluids Engineering-transactions of The Asme – J. Fluid Eng. 129. 10.1115/1.2436580.*
3. *Rajesh N., Ramesh Babu N. Optimization of parameter in water jet peening process. International Conference on Shot Peening and Blast Cleaning; India; 2001. p. 239–249.*
4. *Toenshoff H. K., Kroos F., Marzenell C. High pressure water peening – a mechanical surface strengthening process. CIRP Ann Manuf Technol. 1997; 46: 113–116.*
5. *Nithyarani, N. Implementation of OPC-Based Communication between Temperature Process and DCS on Labview Platform.*
6. *Masataka Ijiri, Daichi Shimonishi, Daisuke Nakagawa , Toshihiko Yoshimura., Effect of water jet peening using ultrasonic waves on pure Al and Al-Cu alloy surfaces, International Journal of Lightweight Materials and Manufacture (2018).*
7. *Xie, J., & Rittel, D. (2018). The effects of waterjet peening on a random-topography metallic implant surface. European Journal of Mechanics - A/Solids, 71, 235–244.*
8. *R. Muruganandhan, M. Mugilvalavan, K.Thirumavalavan, N. Yuvaraj. "Investigation of water jet peening process parameters on AL6061-T6", Surface Engineering, 2017.*
9. *Arola, D., Mccain, M. L., Kunaporn, S., and Ramulu, M. (2002). Waterjet and abrasive waterjet surface treatment of titanium : A comparison of surface texture and residual stress, 249, 943–950.*
10. *Erfan, Osama., El-Nasr, A., BA, A., & Al-Mufadi, F. (2014). Erosion-corrosion behavior of AA 6066 Aluminum alloy. IJME, 3, 15-24.*
11. *Daniewicz, S. R., and Cummings, S. D. (1999). Characterization of a Water Peening Process. Journal of Engineering Materials and Technology, 121(3), 336.*
12. *Sonde, E., Chaise, T., Boisson, N., and Nelias, D. (2018). Modeling of cavitation peening: Jet, bubble growth and collapse, micro-jet and residual stresses. Journal of Materials Processing Technology, 262, 479–491. doi:10.1016/j.jmatprotec.2018.07.023.*
13. *Khudhair, M. R., and Mallarapu, M. G. K. Frequency Responses of Aluminum A356 based on High Strength Alloy Composite (HSAP).*

14. *Arola, D., Mccain, M. L., Kunaporn, S., &Ramulu, M. (2002). Waterjet and abrasive waterjet surface treatment of titanium : a comparison of surface texture and residual stress, 249, 943–950.*

15. *Yamuchi Y, Soyama H, Adachi Y, et al. Suitable region of high-speed submerged water-jets for cutting and peening. J SME Int J B.1995; 38: 31.*

16. *Daniewicz, S. R., & Cummings, S. D. (1999). Characterization of a Water Peening Process. Journal of Engineering Materials and Technology, 121(3), 336.*

17. *Sonde, E., Chaise, T., Boisson, N., &Nelias, D. (2018). Modeling of cavitation peening: Jet, bubble growth and collapse, micro-jet and residual stresses. Journal of Materials Processing Technology, 262, 479–491. doi:10.1016/j.jmatprotec.2018.07.023.*

18. *Khudhair, M. R., & Mallarapu, M. G. K. Frequency Responses of Aluminum A356 based on High Strength Alloy Composite (HSAP).*